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Technical Report S-272

HYDROGEN FLUORIDE CHEMICAL LASER- A DEMONSTRATION OF PURE CHEMICAL PUMPING III. CHEMICAL PUMPING IN A LAMINAR DIFFUSIVE-MIXING LASER SYSTEM

by

Joseph F. Spinnler

96

November 1970

U. S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA 35809

Contract DAAH01-70-C-0146, P001

ROHM AND HAAS COMPANY
REDSTONE RESEARCH LABORATORIES
HUNTSVILLE, ALABAMA 35807

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FOREWORD

The work in this report was conducted under Contract DAAH01-70-C-0146, P001 for research on high-energy chemical lasers under the technical cognizance of APL&C, Research and Engineering Directorate, U. S. Army Missile Command, Redstone Arsenal, Alabama. The specific objective of the laser contracts at these Laboratories has been to demonstrate continuous laser action by stimulated emission of hydrogen fluoride pumped solely by the energy released by the homogeneous chemical reaction between hydrogen and fluorine.

Neither the suitability of HF as an emitter nor the efficacy of H_2–F_2 pumping had been demonstrated at the time work began. Since then, single-pulse laser action of H_2–F_2 has been demonstrated (within the first year's contract), and stimulated emission of HF excited by external means has been reported by other investigators.

Successful chemical pumping by hydrogen and fluorine in a continuous-flow system to excite stimulated emission of carbon dioxide has been reported in the literature. More recently, pumping of CO_2 via HF and DF, and the pumping of HF using the energy of chemical reaction alone has been reported, with the latter investigations having been accomplished concurrent with successful results in these Laboratories.

This report is the fourth of a series detailing the laser work in the Redstone Laboratories. The first report (S-139, July 1967) gave the results of gain calculations to determine the energy distribution theoretically achievable in HCl and HF as emitters. The second report (S-163, May 1968) described the design and construction of the apparatus, as well as the experimental results obtained during the first year of investigation, culminating in the successful demonstration of pure chemically pumped laser action with hydrogen and fluorine in a single-pulse system. The third report dealt with progress toward a continuous-flow system, including construction of an improved fast-mixing injector to supersede the impinging-jet system used earlier, and various methods of inducing population inversion through introduction of a third species such as NO or fluorine atoms.

This report constitutes the final report on Contract DAAH01-70-C-0146, P001 and, together with the preceding reports under Contracts DAAH-01-67-C-1475 and DAAH01-69-C-0206, covers all the laser work in these Laboratories.

The author wishes to acknowledge the help and advice of our consultants, Professors S. H. Bauer of Cornell University and C. Bradley Moore of the University of California (Berkeley), and the assistance of Professor T. A. Cool of Cornell University for his design of the laminar diffusive burner.

We also acknowledge the assistance of the personnel of the Rohm and Haas Redstone Research Laboratories Engineering Design Group and the excellent job of fabrication of the required equipment by the personnel of the Mechanical Instrument Shop. The assistance of personnel of the Instrument Development Group in detector instrumentation and design and fabrication of the safety system is greatly appreciated. The contributions of technical assistants Messrs. J. W. Clark, W. F. Hooper, and W. M. Davis are also gratefully acknowledge.

Captain William Glass of the Physical Sciences Laboratory, R&E Directorate, U. S. Army Missile Command also assisted in the work covered in this report. Captain Glass's faith in the project, his efforts in obtaining funding, and assistance in the experiments contributed infinitely to the measure of success that was obtained.

ABSTRACT

This report describes results of continuing experiments in a laminar-diffusive mixing laser system. Conclusive evidence for CW coherent laser action of hydrogen fluoride is offered, with pumping energy supplied solely by the energy of chemical reaction. Flow conditions of H_2 and F_2 and other fuels and reactant gases are also presented.

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TABLES

FIGURES

Section 1. INTRODUCTION

The objective of the laser research at the Redston Research Laboratories of Rohm and Haas Company was the demonstration of a continuous chemically pumped laser; i.e., the chemical energy of molecular reactions generates population inversion in a reactant species. Most lasers require an external pumping system such as flash lamps, electrical discharge, or arc heating of reactant species. This report describes experiments conducted in these Laboratories using a laminar diffusive-mixing laser system in which continuous-wave (CW) and coherent energy output was observed. Moreover, pumping energy was available only from gaseous reactions (F_2 + NO and F, F_2 + H_2, H_2), a pure chemical laser.

Earlier work in these Laboratories consisted of theoretical analysis of chemical laser systems (1)[1] and design, construction, and experimentation on two types of laser systems – a single-pulse laser system and a turbulent-flow mixing system (2). During the period reported therein, emission characteristic of laser radiation was observed in the single-pulse laser system. Radiation of a similar character was observed in the turbulent-flow system; however, its laser characteristics could not be verified as was done in the case of the single-pulse laser system in ensuing experiments on these systems (3, 4). Rationale leading to design and construction of the laminar diffusive-mixing laser system and initial experimentation are also detailed in Reference 4.

Work reported herein is a continuation of experimentation with the laminar diffusive-mixing laser system. Various flows, mixture ratios of diluents and reactants, and mixing locations in the system under a variety of cavity pressures were investigated. The F atom forming reaction

$$F_2 + NO \rightarrow NOF + F \qquad (1)$$

was utilized along with various hydrogenated and deuterated reactant fuels. CO_2 was also injected without success. Use of SF_6 was made in order that the system be cryogenically purified.

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[1]Numbers in parentheses refer to references at the end of the report.

CW coherent radiation was observed in the case in which pre-cooled fluorine was used. A hydrogen - nitric oxide fuel and sulfur hexafluoride diluent were used in these successful experiments. Low output power prevented characteriaztion of the radiation; however, coherence was verified by determining of the laser cavity.

Section II. EXPERIMENTAL

1. Apparatus

The laminar diffusive-mixing laser system, which includes laser cavity, optical cavity, detector-optical system, gas-metering system, safety system and exhaust system, has been described in detail in References 2 and 3. This system, so described, with minor variations in the plumbing for accommodation of gases and gas mixing locations for various experiments and modifications of cavity optics (variation in mirror reflective surface and focal length), was utilized for the work reported here. The laminar diffusive laser, itself, is shown in Figure 1A. A view of the total system, cavity, optics, reflectors, etc., is shown in Figure 1B.

The optical and detector systems normally utilized are shown in Figure 2. In the experiments in which coherent radiation was detected, the laser cavity mirror (M_1 of Figure 2, the concave mirror) was of 500-mm focal length. This change was made in order that the cavity mode volume might be increased somewhat.

Only the AuGe detector sub-system was useful in the experiments because output intensity was minimal.

A schematic of the flow system is shown in Figure 3. Modifications made involved relocation of various mixing locations for nitric oxide and diluent.

For the experiments in which F_2 and NO were premixed before admission, this mixing was done in the F_2 manifold of the laser cavity (Figure 4). In the experiments in which the F_2 was cooled, F_2 was allowed to flow first through the rotameter, then through a copper coil immersed in a dry ice trichloroethylene bath, which was adjacent to the laser cavity, and then into the F_2 manifold.

2. Experimental Results

The data from experiments for the period covered by this report have been reduced and the results along with comments and observations tabulated in Table I. Flow rates for the experiments are given in cc/sec at STP for the various gases utilized in the experiments. Where sufficient data were lacking, flows and pressures have been estimated and indicated by ( ). A (+) or (-) indicates that flow was

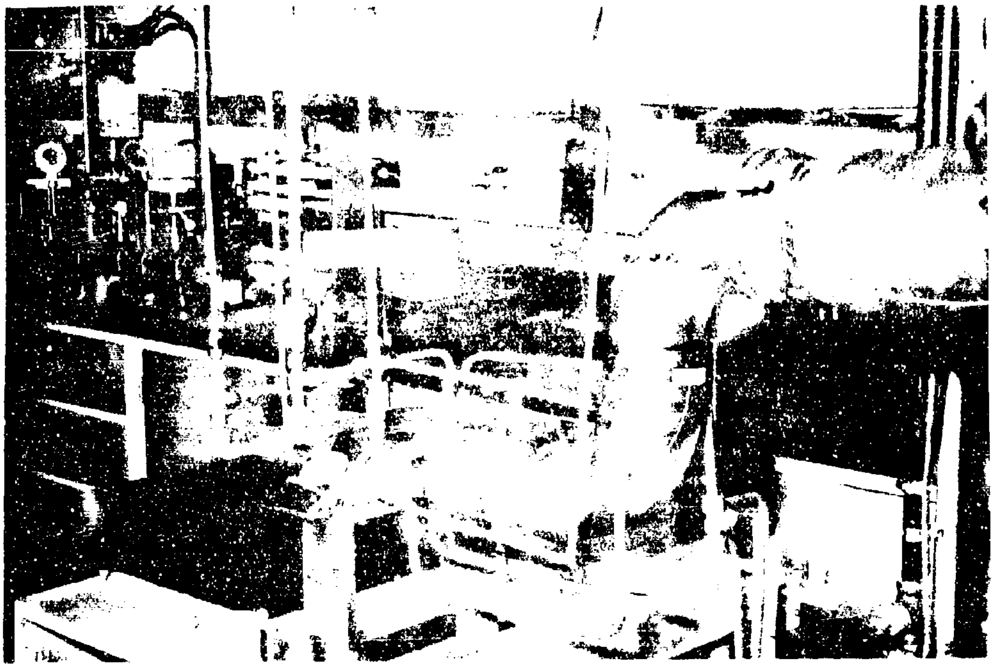


FIGURE 1A. ANGLE [illegible] OF BURNER SYSTEM

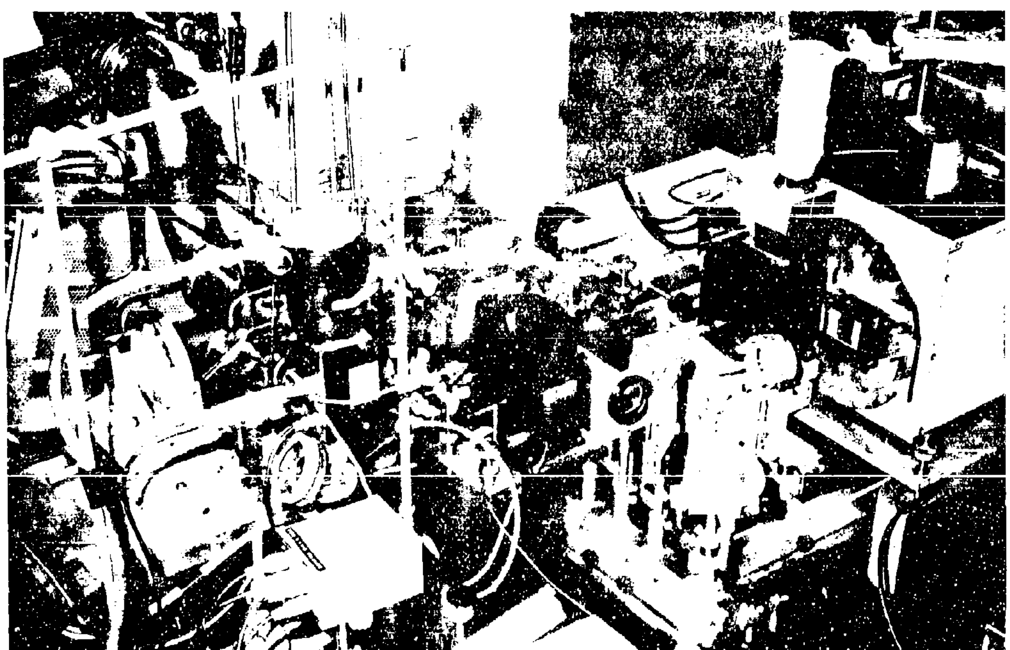


FIGURE 1B [illegible] ER AND OPTICS

FIGURE 1. THE LAMINAR DIFFUSIVE-MIXING LASER SYSTEM

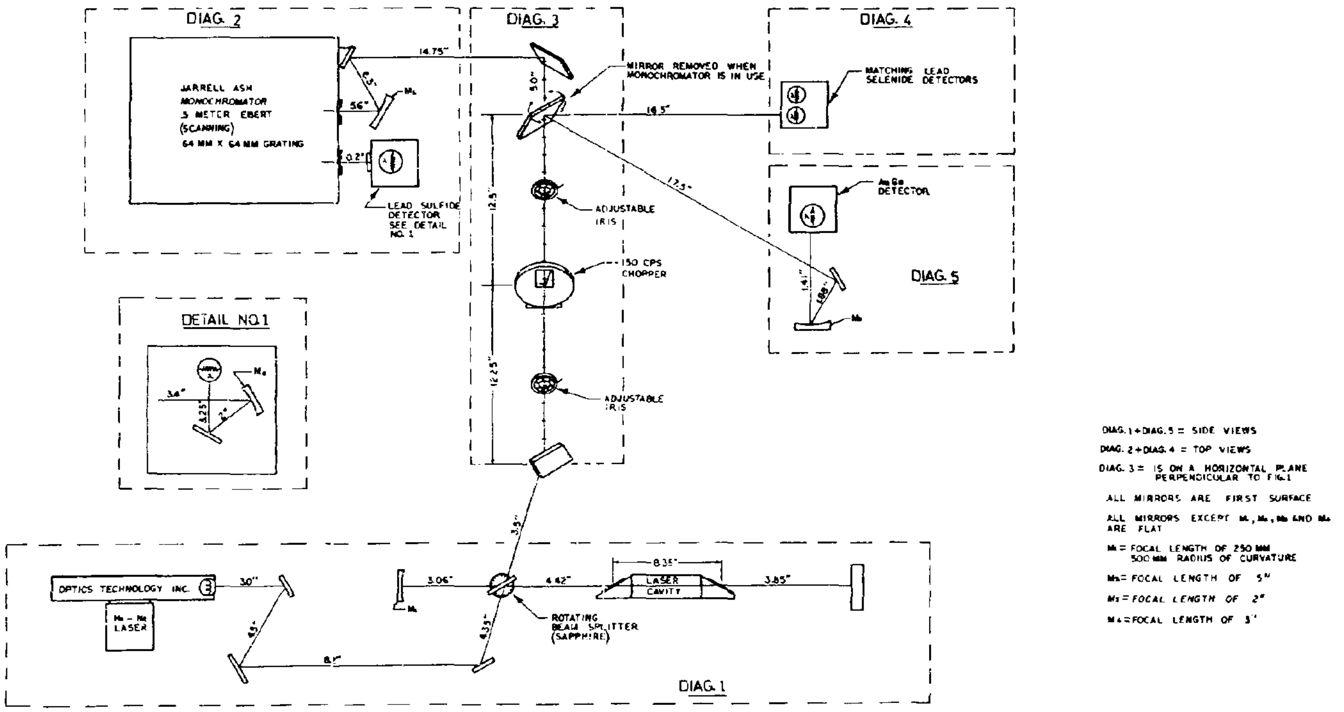


FIGURE 2. SCHEMATIC OF THE OPTICAL AND DETECTOR SYSTEMS OF THE LAMINAR DIFFUSIVE-MIXING LASER SYSTEM

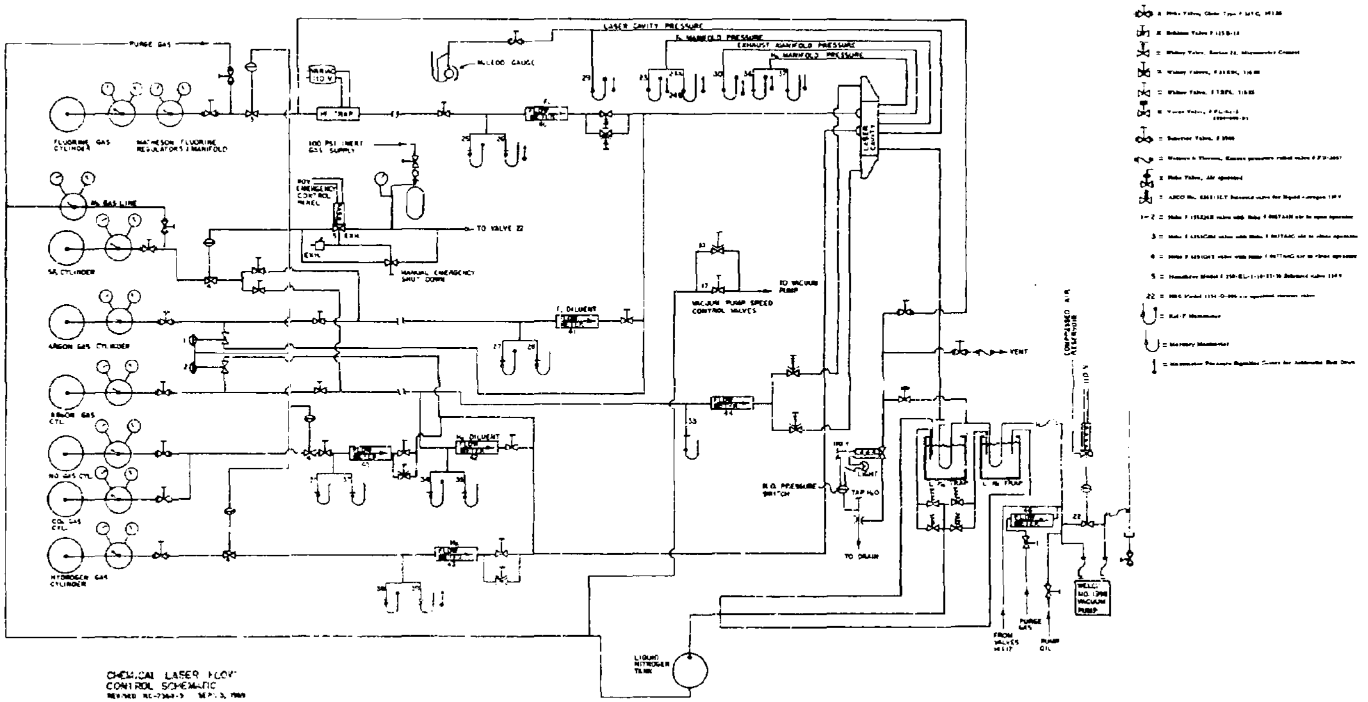
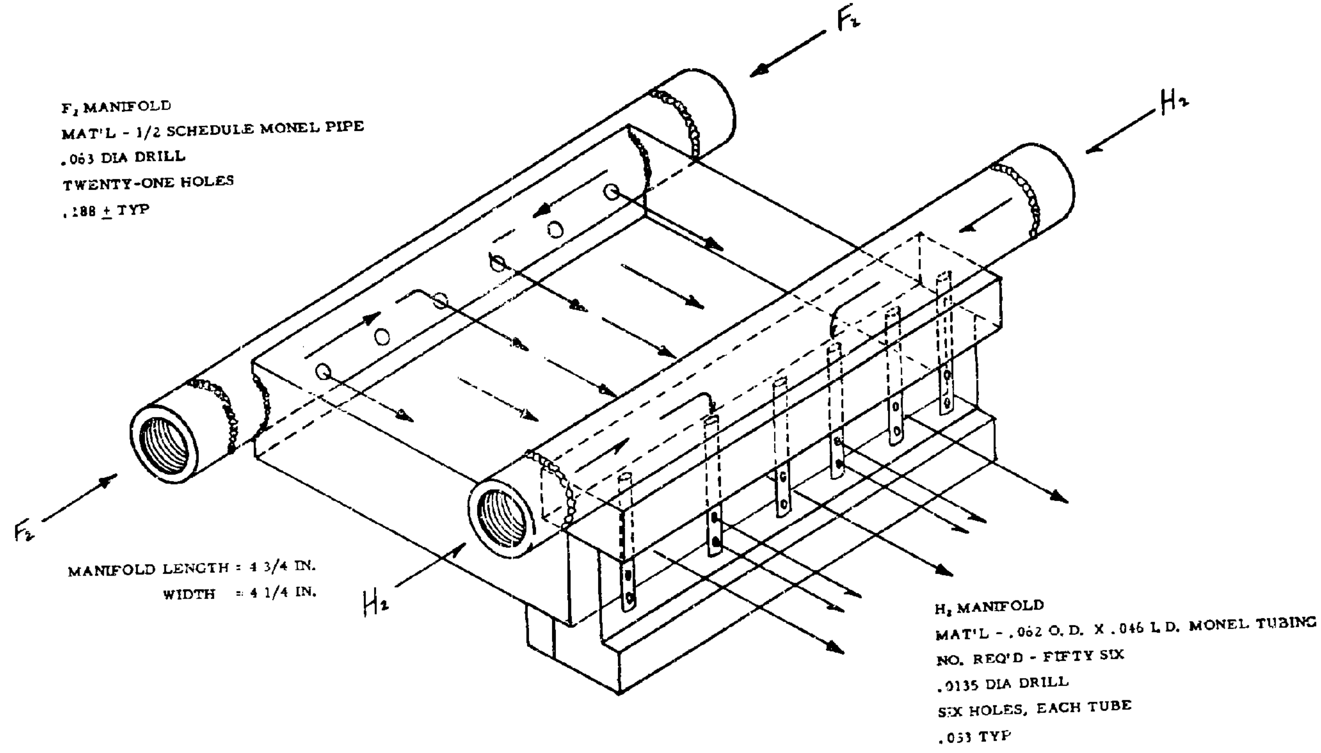


FIGURE 3. FLOW SYSTEM FOR THE LAMINAR DIFFUSIVE-MIXING LASER



FLUID MIXING TECHNIQUE FOR THE HF CHEMICAL LASER

FIGURE 4. SCHEMATIC OF THE FLUID MIXING TECHNIQUE FOR THE HF LAMINAR DIFFUSIVE-MIXING LASER

Table I. Conditions and Observations of the Laminar Diffusive-Mixing Laser Experiments

Cavity Flow Area = 1.008 cm x 10.0432 cm = 10.0512 cm², Flow Velocity = Total Flow (75.613/cavity pressure) (Continued)

Date	Experiment No. and Variation	Flow Rates at STP cc/sec: Oxidizer F_2	Oxidizer F_2 Diluent Ar	Oxidizer F_2 Diluent N_2	Oxidizer F_2 Diluent SF_6	Fuel H_2	Fuel D_2	Fuel CH_4	Fuel NH_3	Fuel Diluent Ar	Fuel Diluent N_2	Fuel Diluent SF_6	Additives Window Purge	Additives NO CO_2*	Flow Conditions: Total Flow	Cavity Pressure (torr)	Flow Velocity (cm/sec at STP)	% HF	Notes
27 Jan	11A															.025			Initial conditions.
	B				155.0	40.0						158.9	.9	5.0	358.9	2.3	11581		SF_6, H_2, NO flows on.
	C	33.0			155.0	40.0						158.0	.9	5.0	391.9	5.9	5523	16.8	F_2 flow on. Orange radiation in cavity. Whistling noise, which increased in pitch.
29 Jan	12A															.020			Initial conditions.
	B				120.0							130.0			250.0	-			SF_6 flow on.
	C			84.0							108.0				192.0	14.5	1001		SF_6 flow replaced by N_2 flow.
	D					20.0									212.0	16.0	1002		H_2, NO flows on.
	E	19.0		84.0		20.0					100.0		.3	5.0	228.3	18.1	954	16.6	F_2 flow on. Orange radiation in cavity.
	F	19.0		84.0		20.0					100.0		.3	3.7	227.0	~(17.9)	954	16.7	NO flow decreased. Same visible radiation as 12E.
	G	19.0		84.0		20.0					100.0		.3	2.8	226.1	~(17.7)	966	16.8	Orange radiation around H_2 inlet ports.
	H													6.6	231.9	-			No change in cavity observations.
	I													5.0	228.3	18.1	954		No change in cavity observations.
	J	14.2													223.5	-			Decreased F_2 flow. Orange radiation in cavity.
	K	14.2		84.0		20.0					100.0		.3	5.0	223.5	~(19.0)	939	12.7	Changed translation stage. Moved cavity mode volume .4" toward H_2 inlet ports. No signal observed on oscilloscope (Au-Ge detector).
	L	19.0			120.0							130.0			294.3	5.1	4363	12.9	Replaced N_2 flow with SF_6 flow. Diffuse orange radiation in cavity. Some signal on oscilloscope.
	M	19.0			120.0	20.0						130.0		4.8	[illegible]	~(4.9)	4523	13.0	Diffuse orange radiation in cavity.
	N													2.2	291.5	-			Same visible radiation as 12M. Cavity mode volume relocated in center position.
	O													4.9	294.2	-			No change in cavity observations.
	P	19.0			120.0	20.0					100.0	130.0		0.0	289.3	~(4.3)	5087	13.1	NO flow shut off. No visible radiation in cavity.
	Q				100.0							64.0			203.3	2.4	6405	18.7	Decreased H_2 diluent flow. No change in cavity observations.
3 Feb	12A															.025			NO mixed with F_2 in F_2 manifold of laser cavity system. Initial conditions.
	B				129.0							129.3			258.3	2.25	8680		SF_6 flow on.
	C			142.6							155.0				297.6	18.3	1230		SF_6 flow replaced by N_2 flow.
	D					20.2							.5	5.0	323.3	21.1	1153		H_2 and NO flows on.
	E	20.0													343.9	22.1	1177	11.8	F_2 flow on.
	F	20.5			129.0	20.2						129.3	.7	5.0	304.8	3.0	7682	13.3	Replaced N_2 flow with SF_6 flow. F_2 manifold became hot.
4 Feb	13A															.05			Initial conditions.
	B				130.2							130.2			260.4	-			SF_6 flow on.
	C			205.0		20.8					228.6		.5	5.0	459.9	26.0	1337		SF_6 flow replaced by N_2 flow.
	D	23.7		205.0		20.0					228.6		.5	5.0	483.6	28.0	1306	8.3	F_2 flow on. NO-F_2 mixing in F_2 manifold. F_2 manifold hot.
	E	23.7			130.2	20.0						130.2	.5	5.0	283.4	3.0	7143	14.2	Replaced N_2 flow with SF_6 flow. Orange radiation in cavity.
	F	23.7			130.2	20.0						130.2	.5	4.0	282.4	~(2.8)	7626	14.2	Orange radiation in cavity. Some signal on oscilloscope (Au-Ge Det). Signal diminished with decrease in NO flow.
	G	23.7			130.2	20.0						130.2	.5	2.7	281.3	~(2.6)	8175	14.2	No radiation.
	H	23.7			130.2	20.0						130.2	.5	6.6	285.0	~(3.3)	6530	14.0	Orange radiation returned after increasing NO flow.
	I													8.3	286.7	-			No change in cavity observations.
	J													10.3	288.7	-			No change in cavity observations.
	K	23.7			130.2	20.0						130.2	.5	2.8	281.2	~(2.6)	8178	14.2	No radiation.
	L	19.7			163.3	20.0						46.0	.3	2.8	252.9	~(3.0)	6374	15.6	Decreased H_2 diluent flow. Orange radiation in cavity.
	M				68.1	20.6						68.5	.4	5.0	202.3	3.0	5099	19.5	No change in cavity observations.
	N	40.0												5.0	212.6	4.0	4019	19.4	Returned SF_6 flows to original flows. Decreased H_2 and F_2 flows. No radiations.
	O	[illegible]			68.1	20.6						68.5	.4	11.7	219.3	~(4.0)	4145	18.9	Increased NO flow. No radiation.
	P													3.4	211.0	-			Cut off NO flow and then increased NO flow until radiation appeared. Orange radiation appeared at indicated flows (P).
	Q				175.0							0.0	0.0		229.0	-			Cut off H_2 diluent flow. No radiation.
	R	30.9			175.0	20.6						0.0	0.0	3.7	229.3	~(3.0)	5779	18.0	Increased NO flow until radiation appeared. Orange Radiation appeared at indicated flows (R).
5 Feb	14A															.025			Initial conditions.

	B			40.1			40.1	.6		80.8	.65	9399		SF_6 flow on.
	C		69.0			77.0		-		146.0	9.0	1380		SF_6 flow replaced by N_2 flow.
	D				16.4			-	5.0	157.4	11.0	1082		H_2, NO flows on.
	E	20.1	69.0		16.4	77.0		-	5.0	177.5	12.0	1118	18.5	F_2 flow on, orange radiation at H_2 inlet ports.
	F	20.1		40.1	16.4		40.1	.6	5.0	122.3	1.3	7113	26.8	Replaced N_2 flow with SF_6 flow. Orange radiation in cavity - diffuse orange radiation around H_2 inlet ports.
	G	20.1		40.1	16.4		40.1	.6	1.8	119.1	1.25	7204	27.5	NO flow decreased. No radiation at first - then orange radiation appeared.
	H	20.1		40.1	16.4		40.1	.6	9.6	126.9	- (2.3)	(4173)	25.9	NO flow increased. Bright orange radiation around H_2 inlet ports.
	I	20.1		40.1	16.4		40.1	.6	12.6	129.9	- (2.9)	(3387)	25.3	Radiation decreased in intensity.
	J						20.0			109.8	-			H_2 diluent decreased. No change in cavity observations.
	K						0.0	0.0		89.2	-			H_2 diluent flow cut off -- no change in cavity observations.
	L	20.1		40.1	16.4		0.0	0.0	- (5.0)	(81.6)	- (1.5)	(4113)	40.2	NO flow increased. Bright diffuse orange radiation downstream of H_2 inlet ports. Radiation brilliant around H_2 inlet ports.
	M			40.0					4.8	81.3	-			F_2 diluent flow increased. No change in cavity observations.
	N						65.8	.8		147.9	-			H_2 diluent flow on. No change in cavity observations.
	O	20.1		0.0	16.4		0.0	0.0	0.0	36.5	- (2.0)	(1380)	89.9	NO flow off. SF_6 flow shut off. H_2 rich. Blue radiation flashes in cavity.
	P	10.2		18.0	10.8		18.4	.6	5.0	63.0	.8	5955	32.4	All flows on and cut back from original settings. Orange radiation in cavity.
	Q	10.2		18.0	10.8		18.4	.6	- (5.0)	(63.0)	- (1.0)	(4764)	32.4	NO flow decreased - radiation diminished. Disappeared when NO flow shut off.
	R						0.0	0.0		44.0				H_2 diluent cut off. No radiation observed.
	S	10.2		18.0	10.8		0.0	0.0	4.9	43.9	.5	6639	46.5	NO flow on. Orange radiation visible around H_2 inlet ports.
	T				-						-			H_2 flow decreased. No change in cavity observations.
	U	10.2		0.0	- (10.8)		0.0	0.0	4.9	25.9	- (2.0)	(979)	78.8	SF_6 diluent flows off. No change in cavity observations at first, then blue radiation flashes.
18 Feb	15A										.025			Initial readings.
	B			83.0			85.0			168.0	-			SF_6 flow on.
	C		96.0		41.8	101.0				238.8	-			SF_6 flow replaced by N_2 flow. H_2, NO flows on.
	D		49.7			59.0			5.0	155.5	-			N_2 flow reduced.
	E	35.6		83.0	37.0		85.0	.4	5.0	246.0	36.4	511	29.[illegible]	F_2 flow on, N_2 flow replaced by SF_6 flow. Purple [illegible] around H_2 inlet ports changed to orange as system pumped down.
	F	35.6		83.0	37.0		85.0	.4	3.6	241.4	(36.2) -	(511)	29.1	Orange radiation flickering in cavity.
	G	35.6		83.0	37.0		85.0	.4	0.0	230.8	(35.6) -	(512)	29.6	No radiation.
	H	35.6		83.0	- (37.0)		85.0	.4	5.0	215.8	(36.0) -	(5[illegible])	29.[illegible]	F_2 rich. Orange radiation.
	I	6.5		74.0	10.6		85.0	.6	5.5	182.2	5.20	2619	7.[illegible]	No change in cavity observations.
	J								11.3	138.9	-			Increased NO flow and then cut off NO flow. No change in cavity observations.
	K	7.0		74.0	10.6		85.9	.6	4.9	182.1	7.9	1713	7.7	F_2 cooled with liquid N_2 trap in F_2 [illegible]. Orange radiation in cavity and around H_2 inlet ports.
	L	35.0		83.0	37.0		85.0	.4	5.0	245.4	- (35)	(531)	25.5	Bright orange radiation around H_2 inlet ports.
	M	35.0		83.0	37.0		85.0	.4	10.0	250.4	- (36)	(526)	26.0	Orange radiation intensity fluctuating with fluctuating F_2 pressure.
	N	35.0		83.0	37.0		85.0	.4	0.0	240.4	- (34)	(535)	29.1	Radiation disappeared.
20 Feb	15A										.2			NO flow mixed with H_2 flow. F_2 cooled by dry ice trichloroethylene bath adjacent the laser cavity. SF_6 diluent mixed with the cold F_2 in F_2 manifold. Initial conditions.
	B			85.0			85.0	.6		170.6	.2	6450		SF_6 flow on.
	C		53.0		43.8	56.0			5.4	158.8	64.7	196		SF_6 flow replaced by N_2 flow. H_2, NO flows on.
	D										74.7			Final readings before adding F_2.
	E	10.2		85.8	43.0		85.0	.6	5.4	230.0	(30) (decreasing)	(580)	8.0	F_2 flow on, N_2 flow replaced by SF_6 flow. Orange radiation around H_2 inlet ports.
	F								2.7	227.3	-			Decreased NO flow. No change in cavity observations.
	G	9.4		85.8	43.0		85.0	.6	0.0	223.8	(25) -	(677)	8.4	Diffuse orange radiation in cavity.
	H	9.4		85.8	43.0		85.0	.6	.4	224.2	(25) -	(678)	8.4	Orange radiation. Signal on oscilloscope. (Au-Ge Detector).
	I	9.4		85.8	43.0		85.0	.6	5.4	229.2	(26) -	(667)	8.2	Orange radiation on H_2 inlet ports.
	J	9.4		85.8	43.0		85.0	.6	13.0	236.8	(27.5) -	(651)	7.9	Maximum NO flow. No oscilloscope radiation signal - orange radiation on H_2 inlet ports.
	K	7.4		85.8	11.1		85.0	.6	13.0	190.2	13.6	1058	7.8	Same observations as (J).
	L	39.7		85.8	41.3		85.0	.6	.3	252.7	(12.0)	(1592)	31.4	With NO flow deminishing, a signal which decreased when cavity was spoiled was observed. First sign of laser emission.
21 Feb	16A										.150			Initial conditions.

	B			85.0				84.6	.6		169.6	14.1	897		SF_6 flow on
	C		49.4		41.4		48.7		-	1.0	140.5	56.9	167		SF_6 flow replaced by N_2 flow; H_2, NO flows on
	D	43.0	47.4		41.4		48.7		-	1.0	181.5	- (12.0)	(1156)	45.1	F_2 flow on
	E	40.3		85.0	39.5			84.6	.6	0.0	240.00	11.1	1701	31.6	Replaced H_2 flow with SF_6 flow. Orange radiation. NO flow cut off
	F	40.3		85.0	39.5			84.6	.6	0.0	250.0	11.1	1703	31.6	Oscilloscope signal (Au-Ge Det) appeared. Orange radiation present as NO was pumped out of rotameter. Oscilloscope signal diminished when cavity spoiled. Pictures of oscilloscope signal made. Continuous LASER emission.
	G	25.0		85.0	25.0			84.6	.6	0.0	220.2	- (8.0)	(1939)	22.7	Decreased H_2 and F_2 flows - no radiation
	H	25.0		85.0	25.0			84.6	.6	+	(2251)	- (8.1)	(2100)	22.2	NO flow on - orange radiation, oscilloscope signal
	I	20.6		85.0	26.6			85.0		0.1	217.9	7.4	2227	18.9	Change in oscilloscope signal when cavity spoiled indicating laser emission.
	J	20.6		49.4	26.6			85.0		0.1	182.5	- (7.8)	(1767)	22.6	Same observations as (I).
	K	25.2		105.2	42.0			99.2		>.1	272.3	8.3	2481	18.5	Increase H_2, F_2, and SF_6 flows. Same observations as (I). Photographs of oscilloscope signal taken.
27 Feb	17A											.125			Initial conditions.
	B			85.0				85.0	.6		170.6	1.00	1290		SF_6 flow on.
	C		40.0				42.2		-		82.2	-			SF_6 flow replaced by N_2 flow.
	D				41.4				.6	>.1	124.3	-			H_2 and NO flows on.
	E	27.9									152.2	-			F_2 flow on temporarily, F_2 tank exhausted.
	F	38	40.0		42.5		42.2		.6	<0.1	163.4	- (10.0)	(1236)	46.5	All flows on - blue flashes as system pumped down.
	G	29.5	40.0		33.7		42.2		.6	<0.1	146.1	14.0	789	40.4	Orange radiation - 1/3 of cavity on H_2 inlet port side. Some signal on oscilloscope (Au-Ge Det). Did not vary when cavity spoiled.
	H	47.0	40.0		50.5		42.2		.6	<0.1	180.4	10.6	1287	29.9	Increased flows. Orange radiation near exhaust manifold.
	I									Varied					Some oscilloscope signal when NO varied. No coherent emission.
	J														Same observations as (I).
	K														F_2 pressure varied considerably - not intentionally. Same observations as (I).
	L	47.0	40.0		50.5		42.2		.6		?				Scan made with Jerrold Ash monochromator of cavity output. No emission lines identified.
4 Mar.	17A											1.0			Pump not pumping correctly. Gold surface cavity mirrors used. Initial conditions.
	B											1.30			Conditions before adding diluent flow.
	C			89.0				85.0	.6		169.6				SF_6 flow on.
	D		42.0		41.4		42.0		-	0.1	125.5	42.0	226		SF_6 flow replaced by N_2 flow. N_2 and NO flows on.
	E	40.5	42.0		41.4		42.0		.6	0.1	166.0	17.9	701	48.8	F_2 flow on, N_2 flow replaced by SF_6 flow. Orange radiation at H_2 inlet ports.
	F	21.9	42.0		32.0		42.0		.6	0.1	138.0	13.9	751	31.7	Orange radiation. 3 cm of signal on oscilloscope at 10 mv/cm (Au-Ge Det). Signal decreased to 2 cm when cavity spoiled. LASER emission.
5 Mar	17A	29.3		85.0	29.0			85.0	.6	<.1	229.0	12.7	1364	25.3	Initial conditions not noted - 1.5 cm signal at 10 mv/cm (Au-Ge Det.) at these flow conditions.
	B	27.8								<.1	227.5	-			Radiation on manifold side.
	C	27.8		85.0	29.0			(85.0)	(0.6)	<.1	227.5	- (12.0)	(1434)	24.4	Decreased SF_6 diluent flow (H_2) - radiation moved to H_2 inlet ports.
	D							61.2	.5		203.6	-			Increased SF_6 diluent flow - same observations as 17A.
	E	27.8		85.0	29.0			85.0	.6		227.5	- (12.0)	(1434)	24.4	Original flow conditions - same observations as 17A.
	F	27.8		85.0	29.0			97.4	.7		240.0	16.7	1087	23.2	Increased SF_6 diluent flow. Radiation in exhaust manifold.
	G	38.1		85.0	41.8			97.4	.7	<.1	263.1	14.6	1363	29.0	Increased H_2-F_2 flows to ~40 cc/sec. Radiation at H_2 inlet ports.
	H	38.1		85.0	41.8			97.4	.7	0.0	263.0	- (14.0)	(1421)	29.0	Reduced NO flow - 2 cm signal on oscilloscope. Detuning cavity did not reduce signal intensity. Not LASER RADIATION.
	I	38.1		85.0	41.8			85.0	.6	0.0	250.5	- (14.0)	(1353)	30.4	SF_6 diluent flows returned to initial flow conditions.
	J							85.0	.6	0.0		-			Reduced SF_6 diluent flow (H_2) and reduced NO flow. No LASER emission observed.
	K	49.7		105.0				97.3	.7		252.7	14.9	1283		Increased SF_6 diluent flow - no observed change.
	L	49.7		99.0	49.6			92.0	.7	<.1	291.1	16.0	1376	34.1	Radiation on H_2 inlet ports.
	M	49.7		114.0	49.6			114.2	.8	<.1	328.2	18.6	1334	30.2	Radiation in center of cavity.
	N	28.9		85.0		30.2		85.0	.6	<.1	229.8	2.16	8045	25.2	Deuterium flow on. No radiation
	O	28.9		85.0		30.2		85.0	.6	<.1	229.7	- (2.1)	(8271)	25.2	Reduced NO flow. Blue-green radiation on H_2 inlet ports.
	P	28.9		85.0		30.2		85.0	.6	0.0		- (2.1)			Whistling noise; visible radiation, center spot radiation was yellow with blue edges.
	Q			+				+		0.0		-			Increased SF_6 flow - whistling stopped
	R	-								0.0		-			Orange radiation at H_2 inlet ports
	S	-								<.1					NO added - same observations as 17R.

	T	24.6													No change in observations.
	U	22.1		(85.0)	41.5			(85.0)		<.1	233.7	(4.0)	(4418)	18.9	Flow of H_2 and F_2 returned to 40 cc/sec. Bright blue radiation present in manifold. This traversed to H_2 inlet ports and change in color to orange
6 Mar	18A											3.0			Initial conditions - methane fuel.
	B			45.9				45.9	.3		91.8	-			SF_6 diluent flows on.
	C		+	0.0		20.1	+	0.0	-	0.1	20.2	-			SF_6 flow replaced by N_2 flow
	D	20.0	+				+		-	-	40.2	-			F_2 flow on. Brilliant orange radiation in cavity.
	E	20.0		46.0		20.1		46.0	.3	(0.1)	132.4	- (16.0)	(626)	30.2	SF_6 flow resumed, N_2 flow off. Purple radiation in cavity
	F	17.5		68.0		20.1				0.2	152.1	16.9	681	23.0	No change in cavity observations.
	G	18.9		68.0		20.1		46.0	.3	0.2	153.5	- (17.0)	(683)	24.6	Bright purple radiation in exhaust manifold
	H	18.9		32.5		(decreased)		33.0	.3	0.2	( )	- (15.0)			Reduced CH_4 flow and SF_6 flow. Bright bluish-purple radiation on exhaust manifold side of cavity.
	I	18.9		32.5				0.0	0.0	0.2	( )	- (13.0)			Green radiation on CH_4 inlet ports, some radiation signal observed on oscilloscope (Au-Ge Det.)
	J	(+)		32.5				0.0	0.0	0.2	( )	- (16.0)			F_2 rich. Graphite accumulated on cavity windows.
9 Mar	18A											2.5			Initial conditions - window purge supply changed from H_2 diluent supply to F_2 diluent supply. Methane fuel.
	B			46.0				46.0	.3		92.3	4.2	1662		SF_6 Diluent flow on.
	C		+	0.0		59.2	+	0.0	-	<.1					SF_6 diluent flow replaced by N_2 flow. CH_4, NO flows on.
	D	30.0		46.0		59.2		46.0	.3	<0.1	181.6	(15.0)	(915)	32.2	F_2 flow on. SF_6 flow on in place of N_2 flow. Bluish white radiation in cavity
	E	30.0		46.0		59.2		46.0	.3	0.0	181.5	(14.8)	(927)	32.2	NO flow off. Diffuse blue radiation in cavity.
	F	30.9		46.0		59.9		46.0	.3	<.1	183.2	15.6	888	33.7	No radiation observed.
	G	30.9		46.0		59.9		46.0	.3	(+)	( )	- ( )			NO flow increased. Blue radiation in cavity. Exhaust manifold hot.
	H	30.9		46.0		59.9		0.0	.3		137.2	- (14.0)	(741)	*45.0	Reduced SF_6 flow (CH_4). Blue radiation on exhaust manifold side of cavity.
	I	30.9		(30.0) decreased		59.9		0.0	(0.3)	<0.1	( )	- (13.0)			Reduced SF_6 flow (F_2), increased NO flow. Green radiation appeared at CH_4 inlet ports. Cut off NO flow and radiation remained at ports.
	J	30.9		46.0		59.9		0.0	0.3	<.1	136.9	- (14.0)	(739)	45.1	Increased SF_6 diluent flow. Blue radiation appeared in center of cavity. Green radiation disappeared.
	K	30.9		46.0		59.9		0.0	0.3	<.1		-			Reduced SF_6 flow. Green radiation flashed to CH_4 inlet ports.
	L											(+)			Used N_2 to increase cavity pressure (pump inlet bleed). Green radiation appeared at CH_4 inlet ports.
	M	30.9		46.0		49.9		0.0	0.3	<.1	126.9	- (14.0)	(685)	48.7	Reduced CH_4 flow. Blue-green radiation flashed in cavity.
	N	30.9		46.0		49.9		46.0	0.3	<0.1		- (15.0)			Reduced SF_6 flow. Green radiation appeared at inlet ports. NO flow then reduced and increased. Blue radiation spot appeared and moved to center of cavity.
	O	30.9		(46.0)		49.9		0.0	0.3	<0.1	( )	- (14.0)			Reduced SF_6 diluent flow (F_2). Green radiation appeared over whole cavity. SF_6 diluent off (CH_4). Blue radiation appeared at exhaust manifold.
	P					-						-			Reduced CH_4 flow. Radiation was green on CH_4 inlet port side of cavity, blue on exhaust manifold side.
	Q	30.9		(46.0)		(49.9)		0.0	0.3	<0.1	( )	- (14.0)			Reduced SF_6 diluent flow (F_2). Blue radiation over whole cavity. Orange radiation appeared at CH_4 inlet ports when SF_6 diluent flow cut off (CH_4).
	R			32.5					.2			-			Increased SF_6 diluent flow. Cavity pressure increased with N_2 (pump inlet bleed).
	S	30.9		75.9		49.9		0.0	.2	<0.1	157.2	38.6	308	39.3	Blue radiation across cavity.
	T											-			Cut off N_2 bleed. Blue radiation over whole cavity.
	U	30.3		79.0		35.9		26.1	.5	<.1	171.9	20.0	650	35.3	Blue radiation over cavity. Brighter at exhaust manifold
	V	30.3		79.0		35.9		0.0	0.5	<0.1	145.8	- (16.0)	(689)	41.6	Reduced SF_6 diluent flow (CH_4). Radiation became green and moved to CH_4 inlet ports.
	W			-					-						Reduced SF_6 diluent flow (F_2). Radiation again moved to CH_4 inlet ports.
	X	31.2		79.0		34.4		24.5	.5	..6	170.2	17.9	719	36.7	Bright blue radiation. Exhaust manifold side. Exhaust manifold hot.
	Y					-						-			CH_4 flow reduced. Green radiation at CH_4 inlet ports.
	Z	6.3		46.0		20.3		0.0	.3	(0.6)	73.5	(16.0)	(347)	17.1	No radiation in cavity.
	AA			-					-	-		-			Reduced CH_4 flow and F_2 diluent flow. Increased CH_4 diluent flow. Green radiation appeared at CH_4 inlet ports. Cut NO flow and radiation remained at ports.
	BB	37.4		46.6		61.0		50.3	.3		195.6	14.7	1006	38.2	Blue radiation on exhaust manifold side of cavity
	CC									-		-			Decreased NO flow. Blue radiation moved to center of cavity.
	DD	37.4		0.0		61.0		0.0		(0.6)	98.4	(22.0)	(338)	76.0	Cut off SF_6 flow. Green radiation over entire cavity. Bright green radiation immediately appeared at CH_4 inlet ports.
	EE	37.4		18.9		61.0		0.0		(0.6)	117.3	(19.0)	(467)	63.8	Increased cavity pressure using N_2 (pump inlet bleed). Green radiation appeared at CH_4 inlet ports.

10 Mar	19A												6.1			NH_3 fuel - initial conditions
	B			46.0					46.0			92.4	5.4	2046		Diluent flows on
	C						29.5					171.5	5.6	2552		NH_3 flow on
	D	30.0		46.0			29.5		46.0	.3	.1	231.9	(5.0)	(2297)	39.6	White coating appeared on windows with F_2 flow on
11 Mar	20A												9.7			Initial conditions - H_2 fuel
	B			85.0					85.0	.6		170.6	12.7	1016		SF_6 diluent flows on
	C				30.8						0.1	201.5	-			H_2 flow on
	D	30.0										231.5	-			NO flow on
	E	30.7		85.0	30.8				85.0	.6	0.1	232.2	(19.0)<2.0	(924)	26.1	F_2 flow on. New F_2 tank - orange radiation on H_2 inlet ports. Blue radiation in exhaust manifold
	F	30.7		85.0	31.4				85.0	.6	0.1	234.8	(20.0)	(868)	26.2	Signal on Oscilloscope $1\frac{1}{2}$ cm at 5 mv/sec signal (Au-Ge Det.) decreased to 1 cm when cavity spoiled - LASER radiation
	G	32.0			35.5						<.1	238.2	-			Decreased NO flow. Radiation in centre of cavity. Windows fogged
	H	30.0		85.0	30.0				85.0	.6	.1	230.7	-			Original conditions - fogged windows decreased output signal to zero
12 Mar	20A												16.9			Initial conditions
	B			85.0	30.8				85.0		.1	200.9	32.7	465		SF_6 diluent flow on. H_2 and NO flow on
	C	28.2										229.1	31.1	557	24.6	F_2 flow on.
	D	24.9		85.0	36.0				85.0		<.1	231.0	19.5	905	21.6	Orange radiation in cavity. 2 cm signal at 5 mv/cm on oscilloscope (Au-Ge Det.). Signal decreased slightly when cavity spoiled
	E	35.5		85.0	41.5				97.6		0.0	259.6	22.6	869	27.4	Radiation on exhaust manifold side
	F	25.0		85.0	52.8				85.8		0.0	248.6	20.3	926	20.1	Chopper off. 3 cm (Au-Ge Det.) spiked radiation emanating from cavity and observed on oscilloscope. Visible orange radiation pulsing in cavity and also present on H_2 inlet ports. Small amount of N_2 on at pump bleed inlet
	G	35.0		85.0	52.8				85.8		0.0	258.6	(22.0)	(389)	27.1	3 cm signal at 5 mv/cm on oscilloscope. F_2 tank emptied, terminating experiment.
13 Mar	21A												13.0			Initial conditions, dielectric mirror substituted for gold mirrors in cavity (750 mm RC dielectric, dielectric flat). Pump not pumping correctly
	B			85.0					85.0	.6		170.6	14.0	921		SF_6 flow on
	C				36.2						.1	206.9	-			H_2, NO flows on
	D												32.7			Final readings before addition of F_2 flow
	E	45.5		85.0	36.2				85.0	.6	(0.1)	252.4	(35)	(545)	36.1	F_2 flow on. Orange radiation on H_2 ports.
	F				(+)						-		-			Decreased NO flow, increased H_2 on SF_6 flows.
	G	45.5		99.2	38.8				99.2	.7	-	283.4	14.3	1495	32.1	Radiation observed in exhaust manifold
	H	45.5		99.2	38.8				99.2	.7	(+)	283.8)	(14.5)	(1480)	32.1	Increased NO flow. Radiation moved to cavity center
				(-)					(-)	-			-			Decreased SF_6 and H_2 flow. Orange radiation flickered
	J			(+)					(+)		(+)		-			Increased SF_6 on NO flow. Same observations as (H)
	K	50.0			50.0				-		-					Increased flows to 50 cc/sec on H_2, F_2. Orange radiation was diffuse, radiation center varied with NO flow. 2 cm at 5 mv/cm radiation observed on oscilloscope (Au-Ge Det). Slight variation in signal when cavity spoiled.
	L	34.6		114.1	29.1				113.2		<.1	291.1	15.1	1458	20.0	Decreased flows. Observations same as initial conditions
	M	32.0		85.0		31.7			85.0		.2	233.9	16.4	1079	27.4	Shut off H_2 flow, started methane flow. Blue radiation in exhaust manifold
	N	32.0		85.0		31.7			85.0		(+) A 13)	(234)	(16.4)	(1079)	27.4	Increased NO flow. Did not displace radiation from exhaust manifold.
	O	32.0	30.0			31.7		30.0				123.7	(?)	(?)		Stopped SF_6 diluent flow and started Argon flow. No radiation observed. Windows began to fog
7 Apr	22A												.025			Initial conditions, F_2 cooled, new H_2 tank, 750 mm RC dielectric and flat dielectric form optical cavity. NaF trap baked out prior to this experiment
	B												.025			Initial manometer readings. F_2 manometer pressure < .1 torr, H_2 manometer pressure < 1 torr.
	C			85.0					85.0				1.3			SF_6 diluent flow on
	D				41.4					.6			8.1			H_2 flow on, window purge on
	E										.1		5.4			NO flow on. Final conditions before addition of F_2
	F												-			F_2 leak - all flows except H_2 flow off
	G												-			System pumped down
	H												.015			Initial conditions before restart.
	I			85.0					85.0				1.3			SF_6 diluent flow on
	J				41.4					.6			11.4			H_2, NO and window purge flows on
	K	36.0		85.0	41.4				85.0	0.6	.1	248.3	1.9	9873	29.0	F_2 flow on, dim and diffuse orange radiation in cavity
	L	39.7		85.0	44.0				85.0	0.6	.1	254.4	2.1	9160	31.2	Diffuse orange radiation

NOT REPRODUCIBLE

	M	39.7	54.0	44.0		54.0	-0.6	.1	192.4	1.7	8550	41.5	Decreased SF_6 diluent flow on H_2, no change in radiation
	N	39.7	54.0	44.0		54.0	-0.6	.1	192.5	-			Increased NO flow. Bright orange radiation in cavity on manifold side.
	O	49.5	54.0	50.0		54.0	-0.6	0.2	200.3	3.1	4175	37.9	Decreased H_2 and F_2 flow - orange radiation on H_2 inlet port side.
	P	49.5	85.0	50.0		54.0	-0.6	0.2	219.3	9.3	1946	39.2	F_2 diluent flow at original flow condition. Orange radiation in center of cavity
	Q	49.5	85.0	50.0		85.0	.6	0.2	270.3	9.3	2198	37.9	H_2 diluent flow at original flow condition. Orange radiation moved to exhaust manifold side of cavity.
	R	49.5	85.0	50.0		85.0	0.6	(-10.1	270.2	-			Decreased NO flow - orange radiation moved into exhaust manifold
	S	49.5	(+) 100.0	50.0		(+) 100.0	-0.6	0.1	300.2	-			Increased SF flow. No change in cavity observations
	T	49.5	114.0	50.0		113.0	-0.6	<.1	327.1	11.9	2114	27.2	Some orange radiation in cavity and exhaust manifold.
	U	25.5	85.0	26.9		85.0	.6	<.1	223.0	13.7	1231	22.9	Reduced NO flow, SF_6 at original flows. Diffuse orange radiation on H_2 inlet port side
	V	25.5	85.0	26.9		85.0	0.6	<<.1	223.0	-			No change
	W	25.5	(—)	26.9		(-)	-	<0.1		-			Reduced SF_6 flow. Orange radiation moved to H_2 inlet ports.
	X	25.5	(-)	26.9		(-)		0.0		-			No change.
	Y	25.5	(—)	41.4		(-)		0.0					No change.
13 Apr	23A									0.50			CO_2 and NO_2 flow combined, gold mirrors, 21.0" FL [illegible] form optical cavity, 2 mm coupling hole, KCl windows - initial conditions.
	B			20.1				0.0, 80.5*	100.6	3.0	2536		H_2 flow on.
	C									-			CO_2 flow on and then cut off
	D		50.8			50.1	6.0	.1, 0.0*		3.3			NO and SF_6 diluent flows on
	E	21.4	50.8	20.1		50.1	6.0	0.1, 0.0		2.1			Uncooled F_2 flow on - greenish-orange diffuse radiation in cavity
	F							0.0, 80.5*		-			NO flow stopped when CO_2 flow started (insufficient NO pressure).
	G	20.7	50.8	20.1		50.1	6.0	.2, 0.0*	147.9	3.1	3607	27.2	NO flow on. Orange radiation at H_2 inlet ports.
	H	20.7	50.8	20.1		50.1	6.0	.2, 80.5*	228.4	4.1	4212	17.6	CO_2 flow on - no radiation.
	I	20.7	50.8	20.1		50.1	6.0	0.2, (-)*		-			Reduced, then shut off CO_2 flow. Orange radiation appeared at H_2 inlet ports.
	J	20.7	50.8	20.1		50.1	6.0	(+,-),(+,-)*		-			Varied CO_2 and NO flows. No LASER radiation
	K	0.0	50.8		21.2	50.1	6.0	.6, (0.0)*	128.7	5.4	1802		Switch to deuterium, F_2 uncooled
	L	21.2	50.8		21.2	50.1	6.0		149.3	3.0	3763	28.4	F_2 flow on - [illegible] observed.
	M	21.2	50.8		21.2	50.1	6.0	0.6, 41.1*	191.0	4.6	3140	22.2	CO_2 flow on - no radiation observed.
	N	21.2	50.8		21.2	50.1	6.0	4, 0.0*	149.7	4.6	2461	28.3	Blue radiation with CO_2 flow off.
	O	21.2	50.8		21.2	50.1	6.0	0.4, (+)*		-			CO_2 flow on. Some blue radiation.
	P	21.2	50.8		21.2	50.1	6.0	(+,-)(+,-)*		-			Increased CO_2 flow and then varied CO_2 and NO. No LASER radiation observed.
	Q	0.0	50.8	20.1		50.1	6.0	1.0, 0.0*	128.0	3.7	2616		F_2 cooled. Switch to H_2 initial conditions.
	R	18.0	50.8	22.5		50.1	6.0	1.0	148.4	3.7	1033	24.3	F_2 flow on. Orange radiation on H_2 inlet port side of cavity.
	S	18.0	50.8	22.5		50.1	6.0	1.0, 34.8	182.2	4.7	2931	19.8	CO_2 flow on. Orange radiation over whole cavity.
	T	18.0	50.8	22.5		50.1	6.0	(+), 34.8		-			Decreased NO flow - orange radiation centered in cavity.
	U									-			Slowed pumping speed with N_2. Radiation intensity increased. Shut off N_2
	V	30.7	50.8	41.4		50.1	6.0	34.8*	213.8	2.9	5574	28.7	Increased H_2 and F_2 flow. Varied CO_2 and NO flows. No LASER radiation observed
	W	22.5	50.8		30.1	50.1	6.0	0.0*	159.5	2.4	5025	28.2	Switch to deuterium - initial conditions.
	X	22.5	50.8		30.1	50.1	6.0	(+,-)(+,-)*	159.5	-			Added CO_2. Tried variety of CO_2 and NO flows. Blue radiation observed
	Y	0.0	50.8	40.0		50.1	6.0	-, -*		-			Switch to H_2. Initial conditions
	Z	42.4	50.8	41.4		50.1	6.0			-			F_2 flow on.
	AA	42.4	50.8	41.4		50.1	6.0	.2, 26.0*	216.9	4.4	3727	38.2	Reduced NO flow. Some orange radiation on exhaust manifold side of cavity.
	BB	42.4	50.8	41.4		0.0	6.0	0.2, 26.0	166.8	4.3	2933	49.6	Shut off SF_6 diluent on H_2. No change in cavity observation.
	CC	42.4	0.0	41.4		0.0	6.0	0.2, 26.0	116.0	3.4	2480	71.4	Shut off SF_6 diluent on F_2. Blue radiation on H_2 inlet ports. Orange radiation in cavity.
	DD	42.4	0.0	41.4		0.0	6.0	0.0		-			NO flow off. Orange radiation centered in cavity. No LASER radiation observed

either increased or decreased but could not be estimated. A tape recorder was used to record pressures, flows, etc., during an experiment, and some flow data were sometimes lost by this process.

The experiments in Table I are listed chronologically. For the purpose of discussion, groups of experiments in which certain common features pertain, will be discussed individually.

a. Initial Experiments

The first experiments after reactivation of the laser system following a period of inactivity between renewal of contracts was for system check-out and for familiarization of Captain William Glass, of the Physical Sciences Laboratory who assisted with later experiments, with equipment, procedures. etc. Conditions approximating those reported in Ref. 3 were utilized for check-out of the system, and are listed in the Table. Results obtained were analogous to those reported previously (Experiments 11-12 January and 27-January 29); ie. no laser radiation was observed emanating from the cavity; only visible orange radiation was observed, the location of which could be varied by variation in flow.

Conclusions drawn from the previous series of experiments (Ref. 3) were that failure to observe laser radiation might result from the lack of a sufficient number of emitting species in the cavity mode volume.

When attempts were made to increase cavity pressure and, thereby, the concentration of emitters, excessive heating of the manifold resulted in shut-down of the system. This type of experimentation was then deferred until a means of cooling the manifold was devised.

b. Experiments with Premixed F_2-NO

From the previous experiments it was concluded that an insufficient number of emitters were being generated in the laser cavity mode volume. One possible means of increasing this number is the premixing of the F_2 and NO, thereby allowing a greater concentration of F atoms, via Reaction (1) to build up before injection of H_2 into the flow. This approach has also been used by T. A. Cool and R. R. Stephens in this CW laser system (5) and worked satisfactorily in their glass apparatus.

In the experiments run in the laminar diffusive-mixing laser system (Monel®[1] construction), (12-13 Feb)-(15-18 Feb) reaction occurred at the hydrogen inlet pots. It was assumed that the Monel tubes offered a catalytic surface and hence a stabilizing effect on the reaction zone. This reaction zone, as evidenced by orange radiation, could not be moved downstream except under extreme conditions, i. e., no NO flow or high-diluent flow, etc., and with little chance of observing laser radiation existing.

Since it had been concluded previously that the orange radiation (3) was characteristic of deactivated HF, with the result that attainment is highly improbable when it is observed, further experiments in this configuration were discontinued.

c. Experiments with Pre-cooled F_2

Since it had been observed in previous experiments that the orange radiation could be moved downstream, but not readily so in the case of premixed NO + F_2, it was then concluded that it might be best to ensure that the F_2 passed the H_2 inlet ports while in the molecular state and rely on the reaction (1) to generate the first F atoms. Hopefully, with higher concentrations, this reaction plus the two HF reactions

$$F + H_2 \longrightarrow HF + H \qquad (2)$$

$$H + F_2 \longrightarrow HF + F \qquad (3)$$

could supply sufficient F and activated HF in the cavity-mode volume for laser radiation to be observed. Additionally, catalysis effects should be minimized as the gas flow passes around the H_2 inlet ports.

The flow system was plumbed, as previously described, to accommodate cooling of the F_2 while allowing the diluent to mix with the F_2 in the F_2 manifold of the laser cavity. The NO and H_2 mixing configurations were returned to the normal configuration, i. e., the configuration used before the previous NO-F_2 premix experiments.

CW coherent radiation was first observed under conditions of 15L - 20 Feb. The radiation was observed for periods of 1/2 min. under conditions in which NO flow was rapidly diminishing. The rotameter size used prevented stabilizing conditions satisfactorily.

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[1] Trademark of The International Nickel Co., Inc., Huntington, W. Va.

Even in later experiments with the smallest diameter rotameter and with smallest flow that could be maintained, the minute amount of NO required still remained a problem.

Attempts were made to maximize the amount of radiation, but insufficient intensity was obtained to allow characterizing of the radiation via the monochromator-detector system. Coherence was verified by detuning the cavity (blocking one of the cavity mirrors).

Under the best operating conditions, 16-23 Feb. 1970, a CW signal could be maintained as long as the F_2 and NO flow could be maintained constant (2-5 min.). Estimation of power output was made by comparison of signal of He-Ne laser and approximated 1μ watt for the optical configuration detailed previously with the exception of the 500-mm focal length curved mirror in place of that indicated in the schematic (Fig. 2). The beam splitter was set 5° off the Brewster angle, which for sapphire reflects 0.61% per surface.

Attempts to improve signal output by use of gold surface mirrors 17-4 March were only slightly successful. A greater amount of incoherent radiation was observed along with coherent radiation. Estimated power output was 5μ watts. Again, neither the coherent nor non-coherent radiation was of sufficient intensity to be measured via the monochromator-detector system.

d. Experiments with Other Fuels

Since experimentation time was limited and it was agreed that the original objective had been met, i.e., demonstration of CW coherent emission using only commercial bottled gases and with no external energy sources required, a decision was made to investigate other fuels in the laminar diffusive-mixing laser system. These experiments comprised experiments 17-5 March through 19-10 March.

No evidence of coherent radiation was observed using D_2, CH_4 or NH_3. Blue radiation was observed in the case of D_2 in contrast to the orange with H_2. Blue, green, and violet radiation was observed with CH_4 dependent on flow conditions. Deposits of NH_4F and carbon on the cavity windows limited flow conditions that could be attempted with these fuels. Pressure build-up in the fuel manifold system, (the system as designed for H_2 fuel requires 0.0135-in.-diameter holes in the inlet-port tubes), further restricted the operating range.

e. Concluding Experiments

Since fuels other than H_2 appeared less than promising, the remaining experimentation time was utilized in attempts to characterize the observed coherent radiation of HF and to observe 10.6-micron CO_2 radiation via HF and DF energy transfer to CO_2. The former comprised experiments 20-11 March to 22-7 April in which coherent radiation was observed but little increase in power output was realized even though large flow throughputs were used. Apparently the system is limited by pumping capacity and flow capacity when flows of 40 cc/sec STP or greater for H_2 and F_2 are attempted. While both reaction products and diluent are cryogenically pumped, this capacity must be exceeded in these flow regimes.

Experiments 23-13 April was an attempt to utilize the energy transfer from excited HF or DF to CO_2. This had been accomplished by Cool and Stephens in their system (5). For experiment 23, the CO_2 was premixed with NO and introduced into the fuel line leading to the laser cavity. The optical system was changed to a 2-mm-hole-coupled hemispherical cavity (gold-surfaced flat and 20.5 in. focal length gold-surfaced concave mirror). KCl windows replaced the sapphire windows of the cavity.

Both H_2 and D fuels were utilized; however, no evidence of coherent radiation was observed. Visible orange radiation was observed. This was the concluding experiment; further experimental work on the system, as it has been described, has been terminated.

Section III. DISCUSSION

Upon conclusion of the final experiment in the laminar diffusion-mixing laser system, it appears that realization of high power output from such a system is highly unlikely. The inability to obtain desired concentration levels in the cavity-mode volume is, more than likely, the major deterrent in this system. The device, when coherent radiation was observed, was probably operating near laser threshold. What effects greater pumping rates and fast throughputs might have cannot presently be evaluated.

Doubts currently exist for the suitability of SF_6 as the diluent. It was required in this system because of limited vacuum pumping capacity.

It is significant that coherent CW laser radiation was observed in this system. Output power was miniscule compared with some other types of HF laser systems (6). However, it was in keeping with observations of Cool and Stephens (7), whose system is based on the concept of laminar diffusive mixing even though the axis of observation was different in the two cases; Cool's was axial to the flow while that of this facility's system was transverse to the gas flow.

No further work is contemplated by this facility as all work in this research facility is being terminated.

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13. ABSTRACT

(U) This report describes results of continuing experiments in a laminar-diffusive mixing laser system. Conclusive evidence for CW coherent laser action of hydrogen fluoride is offered, with pumping energy supplied solely by the energy of chemical reaction. Flow conditions of H_2 and F_2 and other fuels and reactant gases are also presented.

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